



Enhanced Nighttime Cloud Retrievals

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<http://www-angler.larc.nasa.gov/satimage/products.html>



Introduction

During daytime, cloud properties such as cloud optical depth (OD), effective particle size Re, and water path (WP) can be derived for a wide range of cloud thicknesses because the reflectance at visible wavelengths is sensitive to changes in optical depth from OD < 1 to OD > 100. At night, information from solar channels is unavailable, so retrievals of the cloud properties are typically limited to clouds having OD < 8, because the cloud is essentially a blackbody at greater optical depths, at least for the window channel wavelengths (10 - 14 μm) typically used for retrievals from satellite imagers. This limitation constrains the monitoring of cloud properties over the full diurnal cycle and leaves a gap in the ability to characterize clouds both at meteorological and climate scales. This paper examines the potential of using the 6.7- μm water vapor channel available on some current imagers and on the GOES-R ABI to cover the full range of ice cloud optical depths that can be determined from radiances measured at night.

Optically thin clouds (COD < 8)

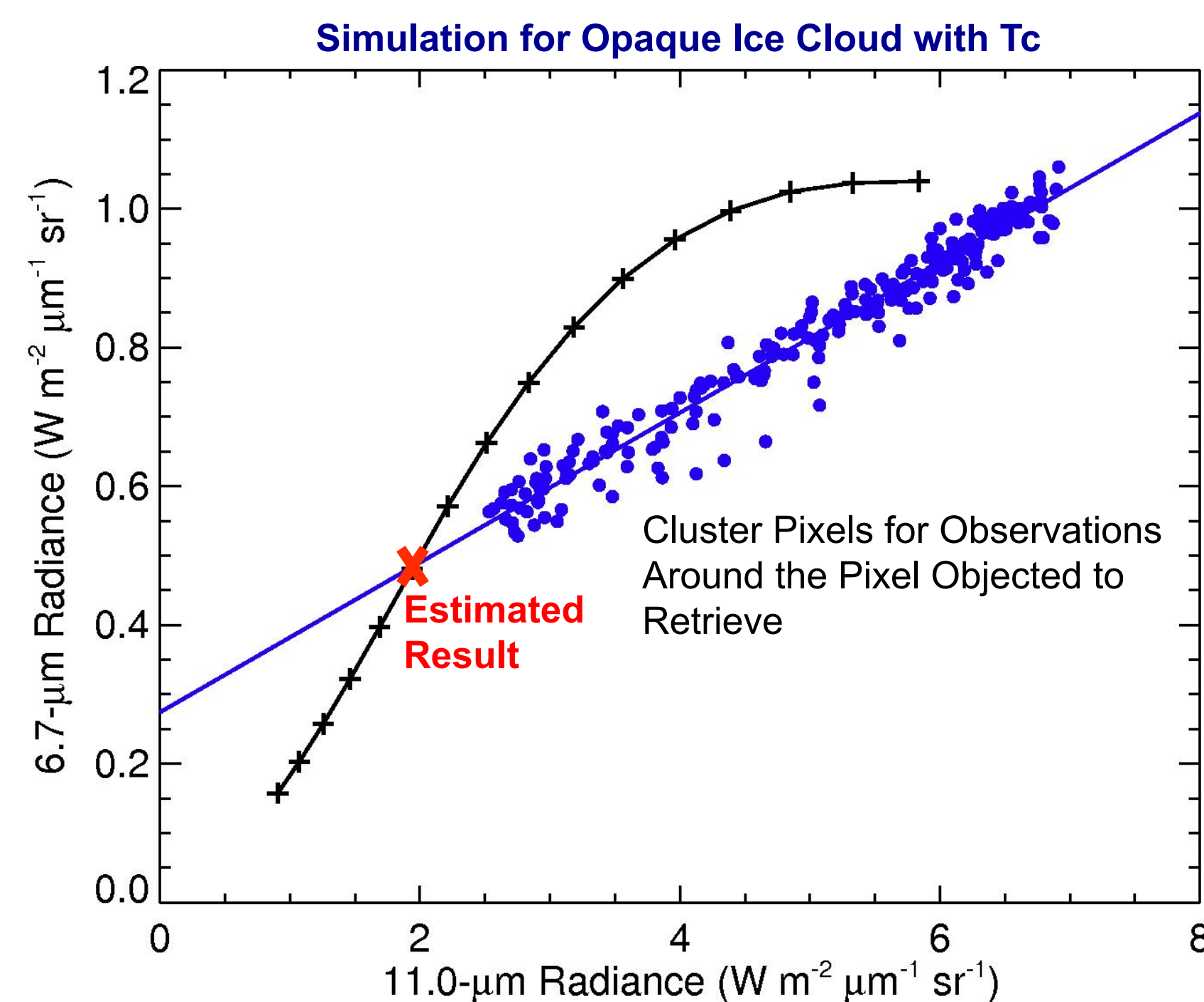
Szejwach (1982) developed a technique using the 10.8- μm (IR) and WV channels to estimate ice COD with following approach for a cloud at effective radiating temperature, Tc.

$$I_{WV} = (1 - N\epsilon_{WV}) \cdot I_{WV}^{clear} + N\epsilon_{WV} \cdot I_{WV}^{cloud}$$

$$I_{11} = (1 - N\epsilon_{11}) \cdot I_{11}^{clear} + N\epsilon_{11} \cdot I_{11}^{cloud}$$

$$\frac{I_{WV} - I_{WV}^{clear}}{I_{11} - I_{11}^{clear}} = \frac{N\epsilon_{WV} (I_{WV}^{cloud} - I_{WV}^{clear})}{N\epsilon_{11} (I_{11}^{cloud} - I_{11}^{clear})}$$

Labels: Clear Sky Radiance, Satellite Measured Radiance, Effective Emissivity, Blackbody Radiance at Tc



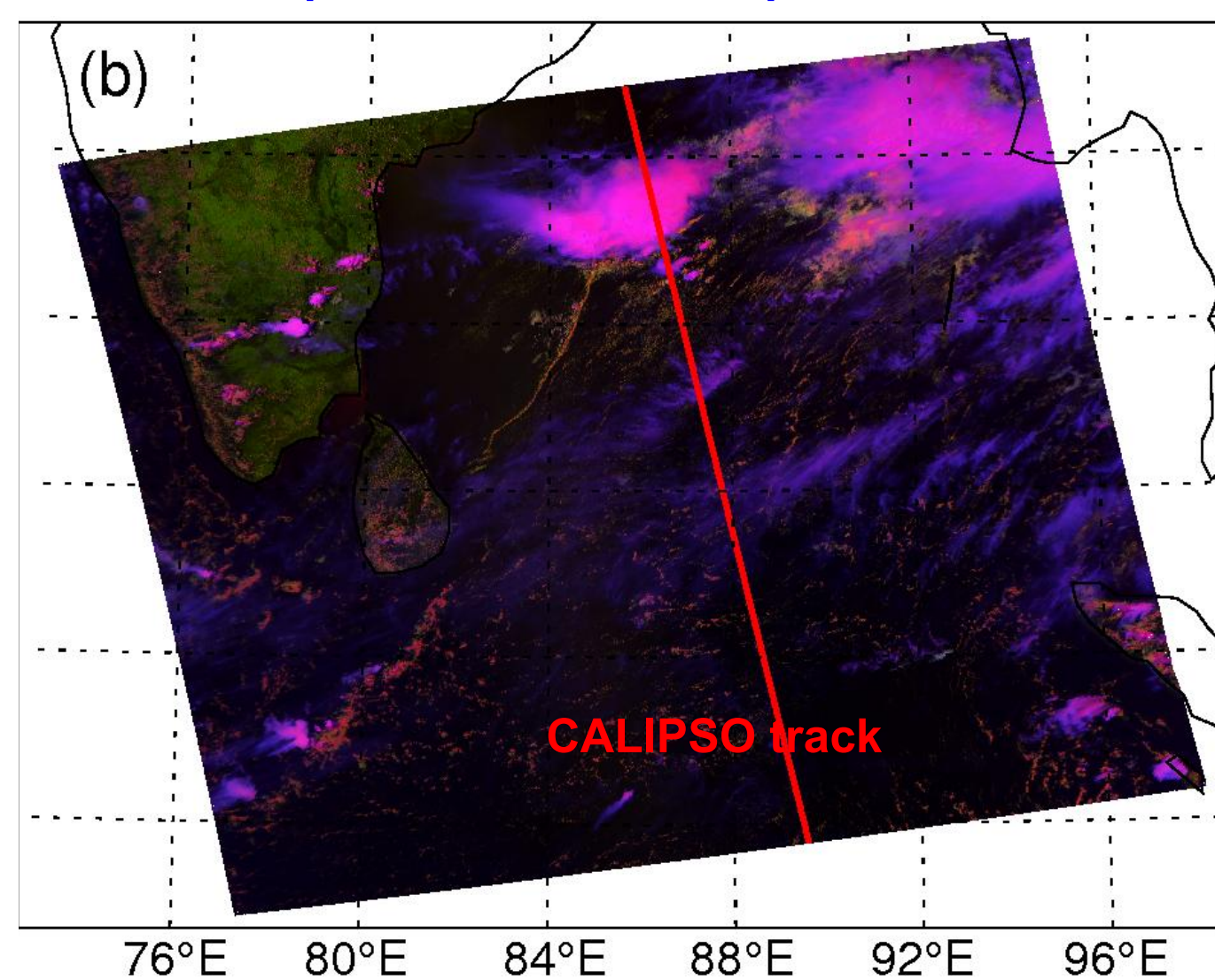
Pixel-based:

- Tc is derived by matching the ratio along black line
- Could be strongly affected by variation of clear sky radiance

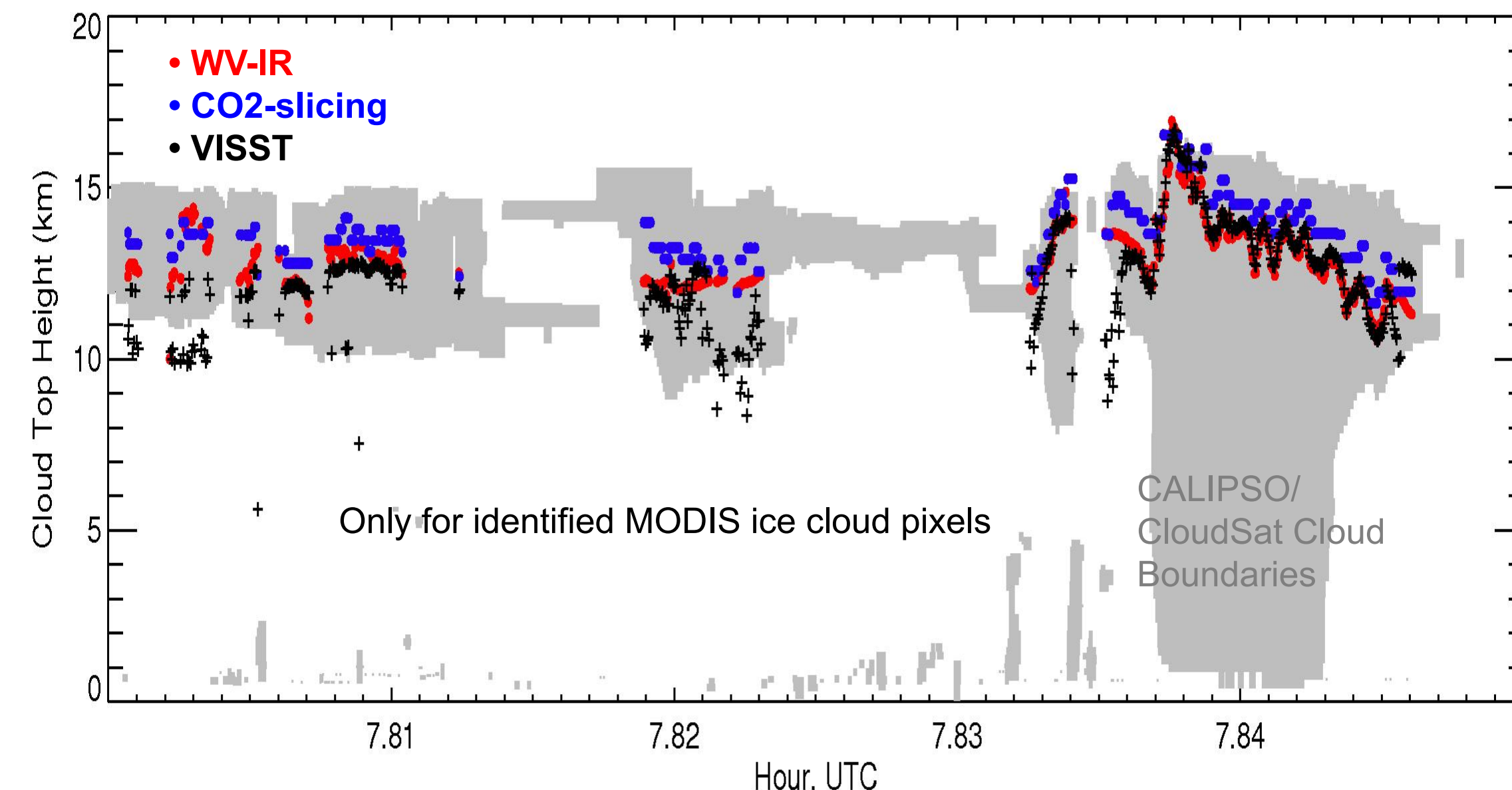
Cluster-based:

- Linear fitting cluster pixels: crosses with simulated opaque ice cloud ratio (black line)
- Could be less affected by variation of clear sky radiance with respect to pixel-based method.

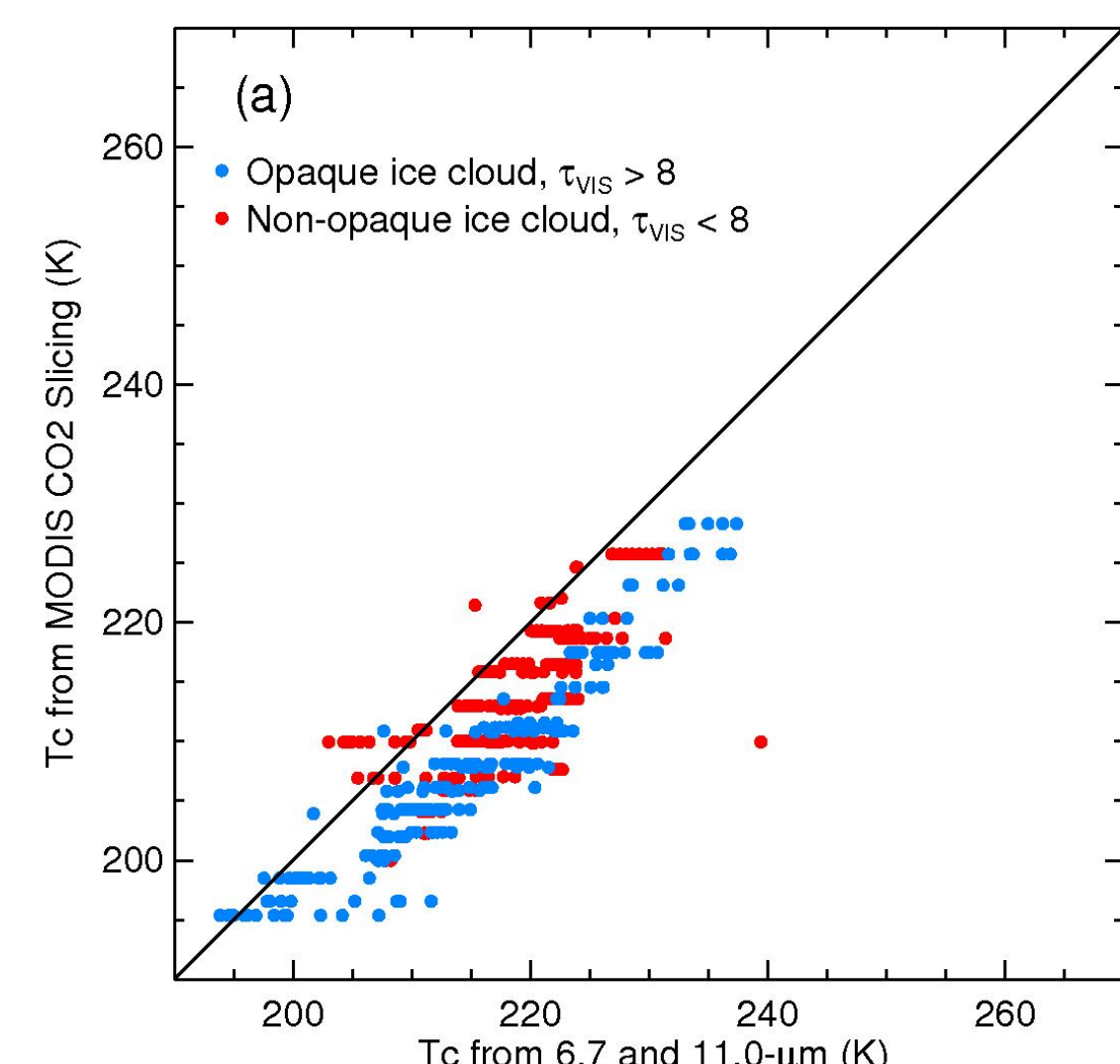
Example: Pseudo RGB, Aqua MODIS 2007.05.22 07:45



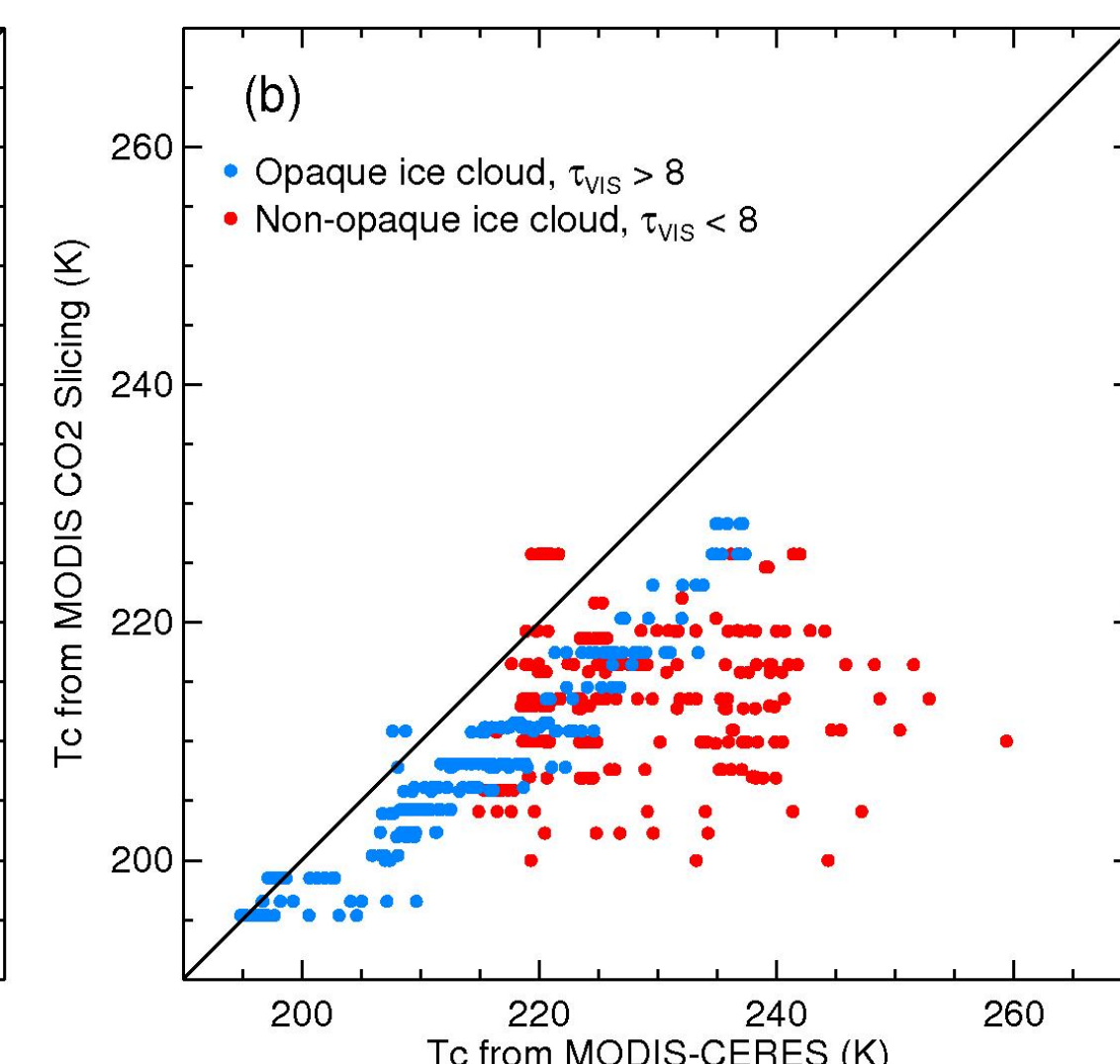
Zc vs. CALIPSO/CloudSat Cloud Profiles



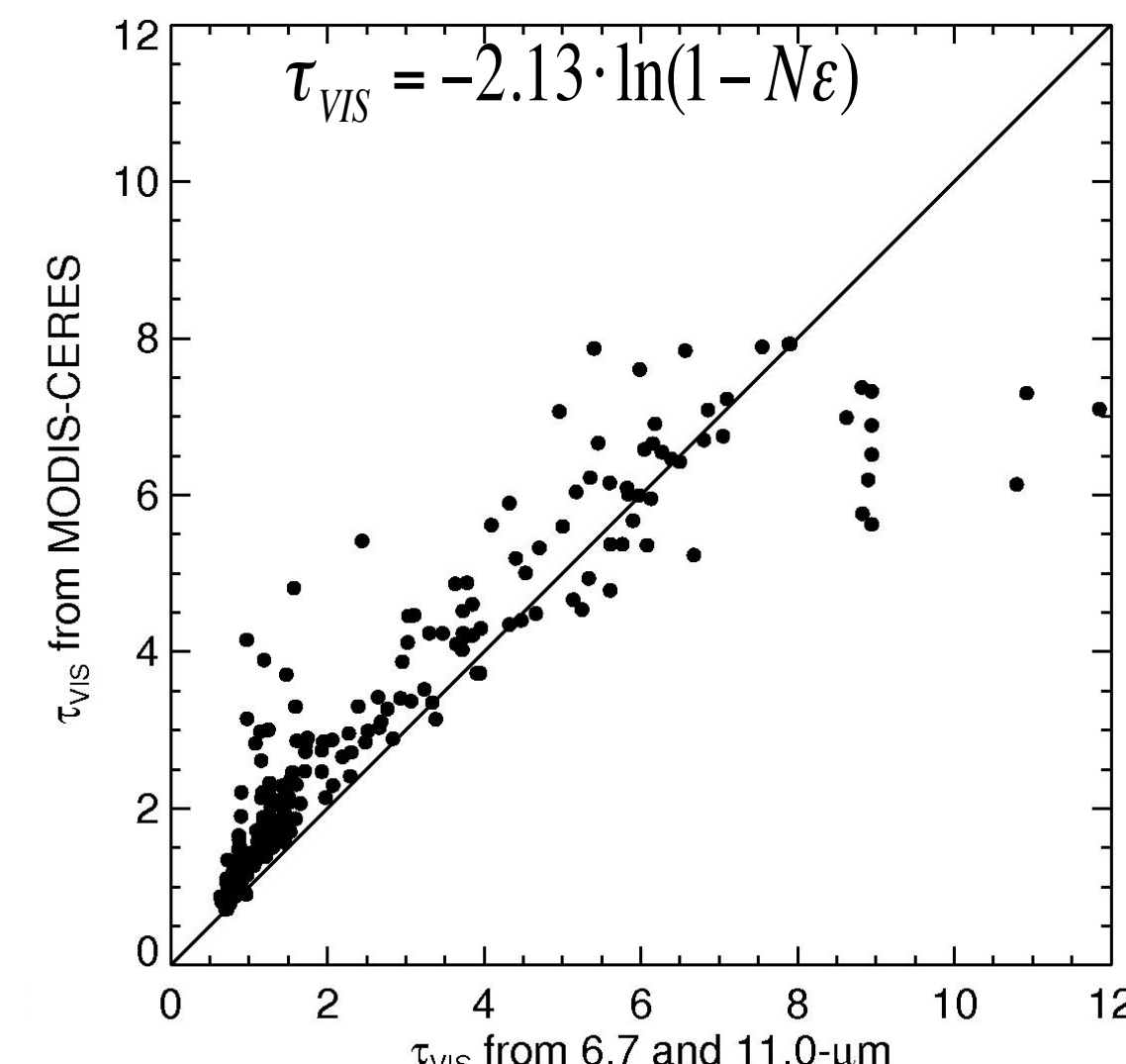
Tc, CO2 vs WV-IR



VISST vs CO2



COD, VISST vs WV-IR



- WV-IR Tc consistent with, but > Tc from CO2 slicing; VISST Tc less consistent with Tc from CO2 slicing
- CERES Ed2 VISST Zc often too low for non-opaque clouds because COD is too large
- WV-IR COD is correlated with VISST COD, but smaller, as expected because VISST COD is too large

Opaque Cloud Retrievals

WV-IR has no sensitivity to COD for COD > 10, e.g., $N\epsilon = 0.99$ for COD = 10; $N\epsilon = 0.999$ for COD = 15; $N\epsilon = 0.9999$ for COD = 20.

Beyond this blackbody limit, we must use other information to infer COD. The following information may be valuable:

1. Cloud vertical inhomogeneity.
2. Relation with environmental parameters, e.g. WV.
3. Location.

The information is incorporated into a **neural network analysis** trained using MODIS data matched with CloudSat/CALIPSO data. The analysis procedure was described in last year's post (Minnis et al., 2010).

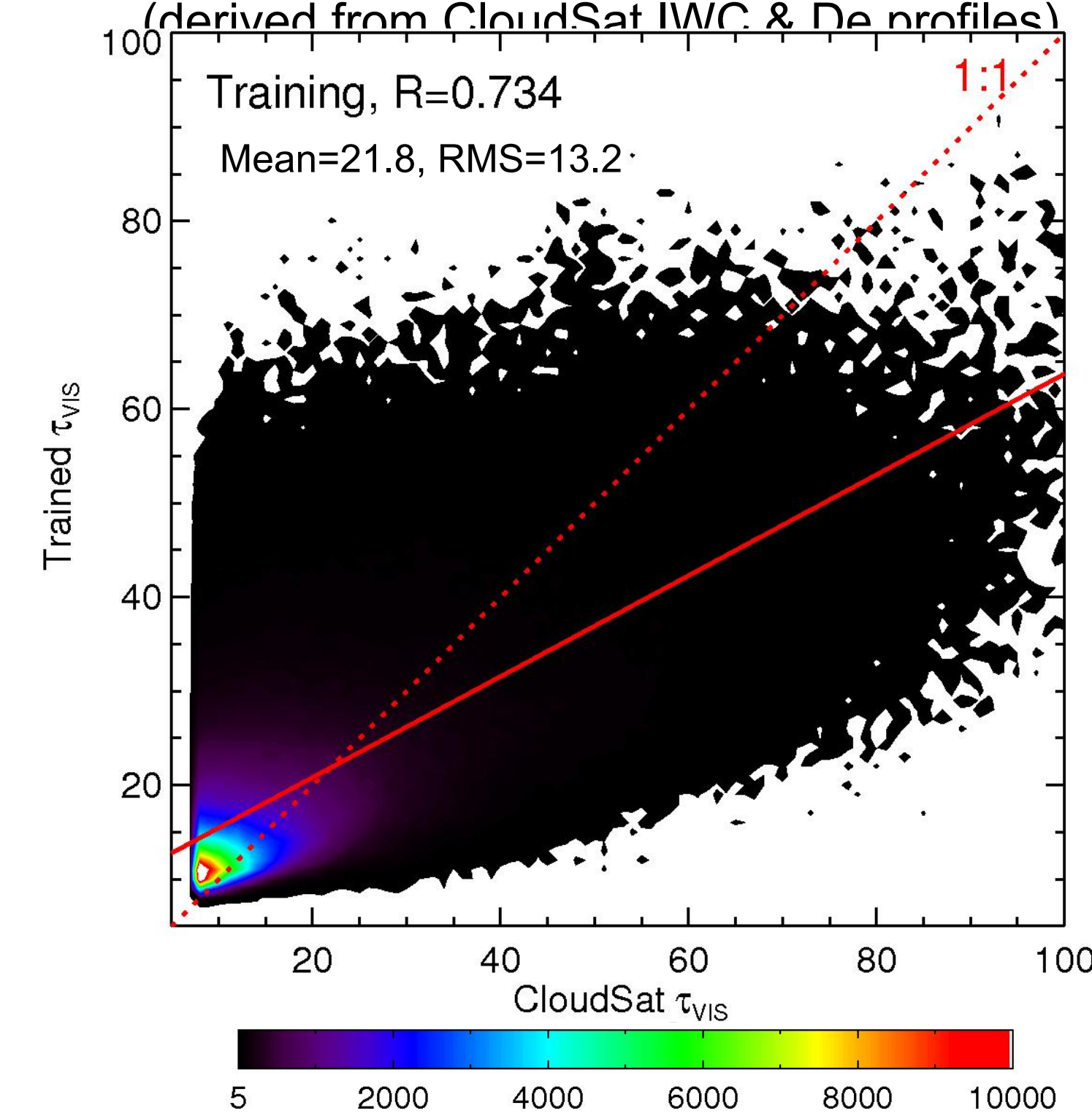
Training data: 2007 LaRC C3M (Kato et al., 2011)

global nighttime data

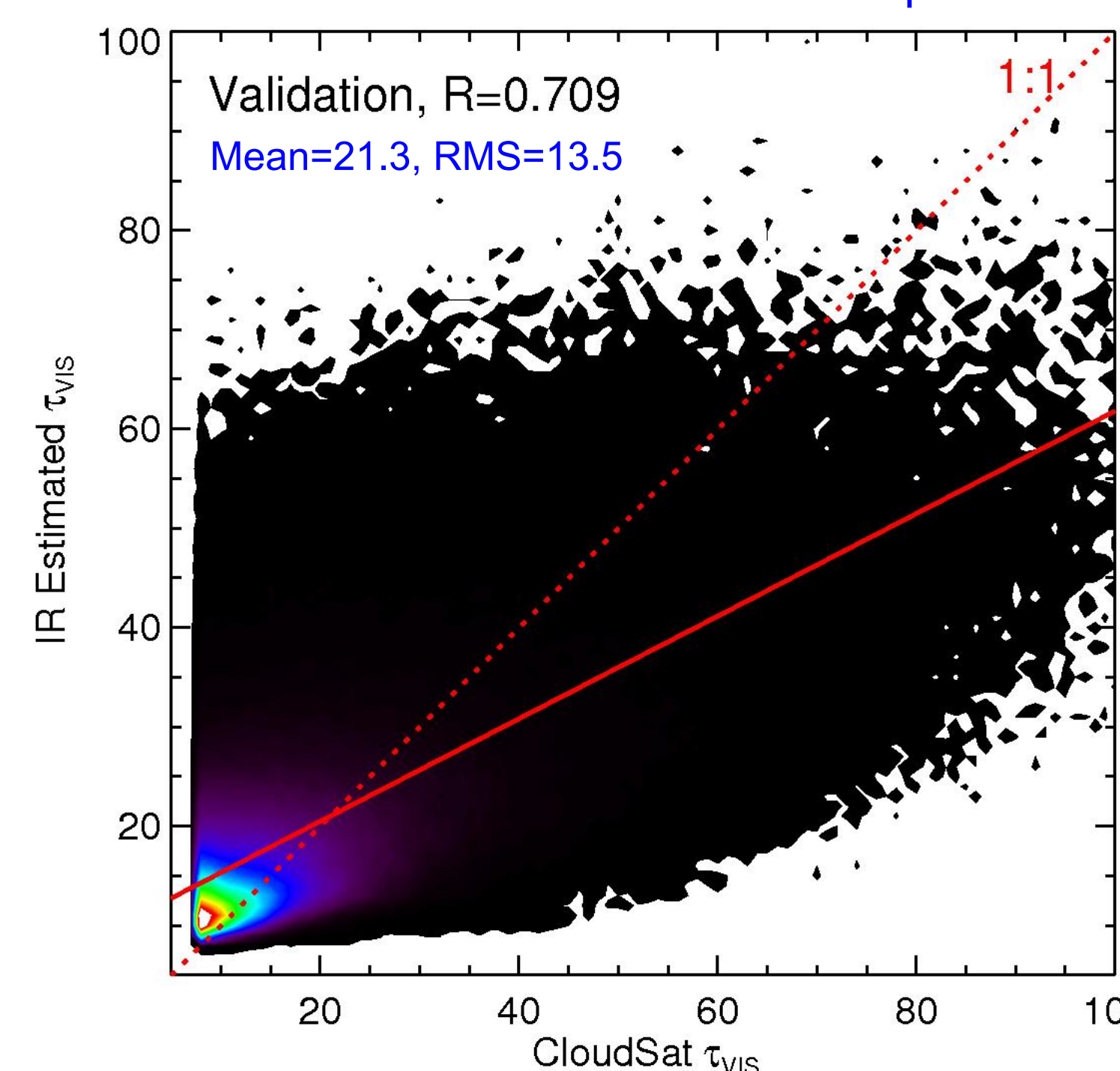
Validation data: 2008 LaRC C3M global nighttime data

Input: MODIS BT3.7, BT6.7, BT11.0, and BT12.0, & their difference
Longitude, latitude; Surface temperature; Satellite zenith ang

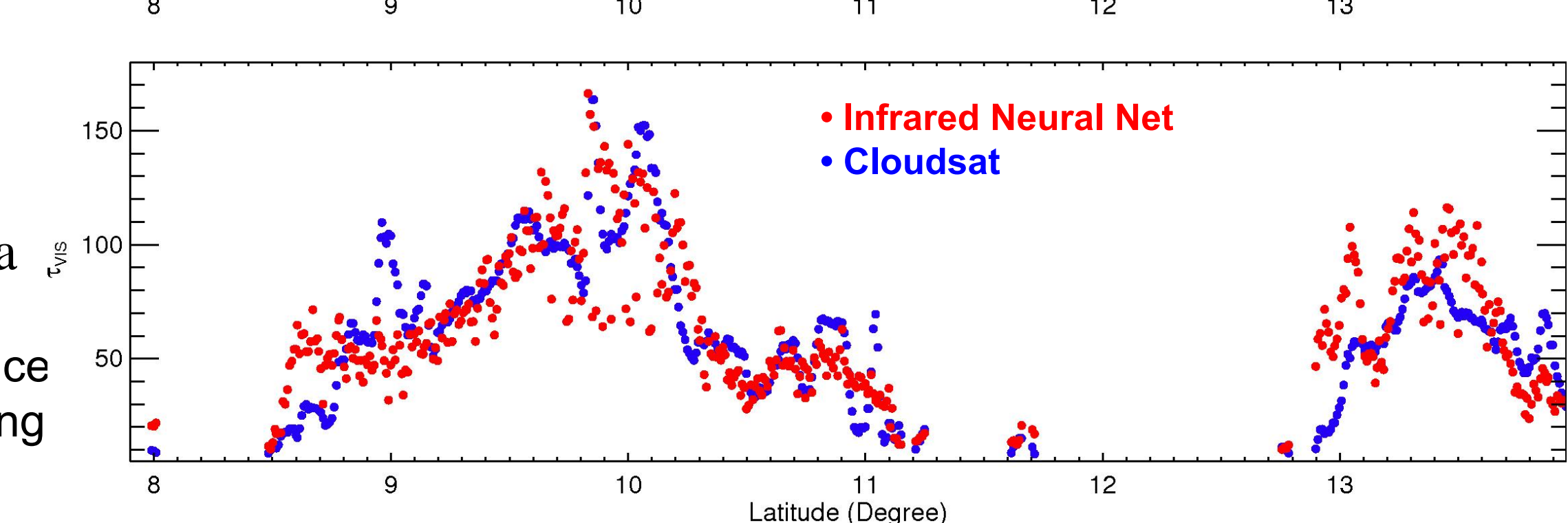
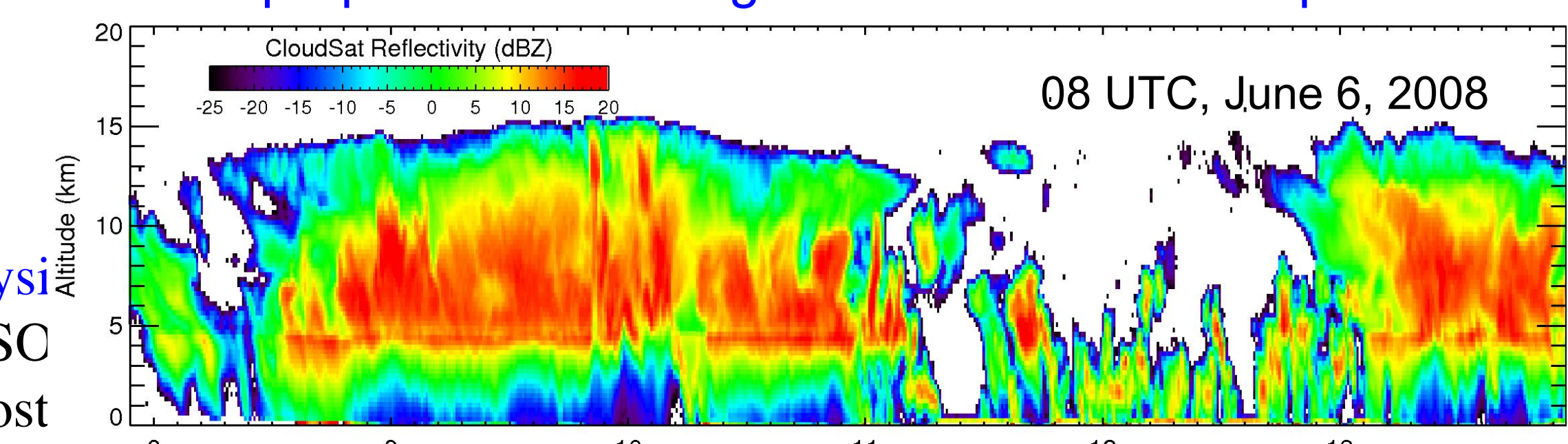
Output: Visible cloud optical depth
(derived from CloudSat IWC & De profiles)



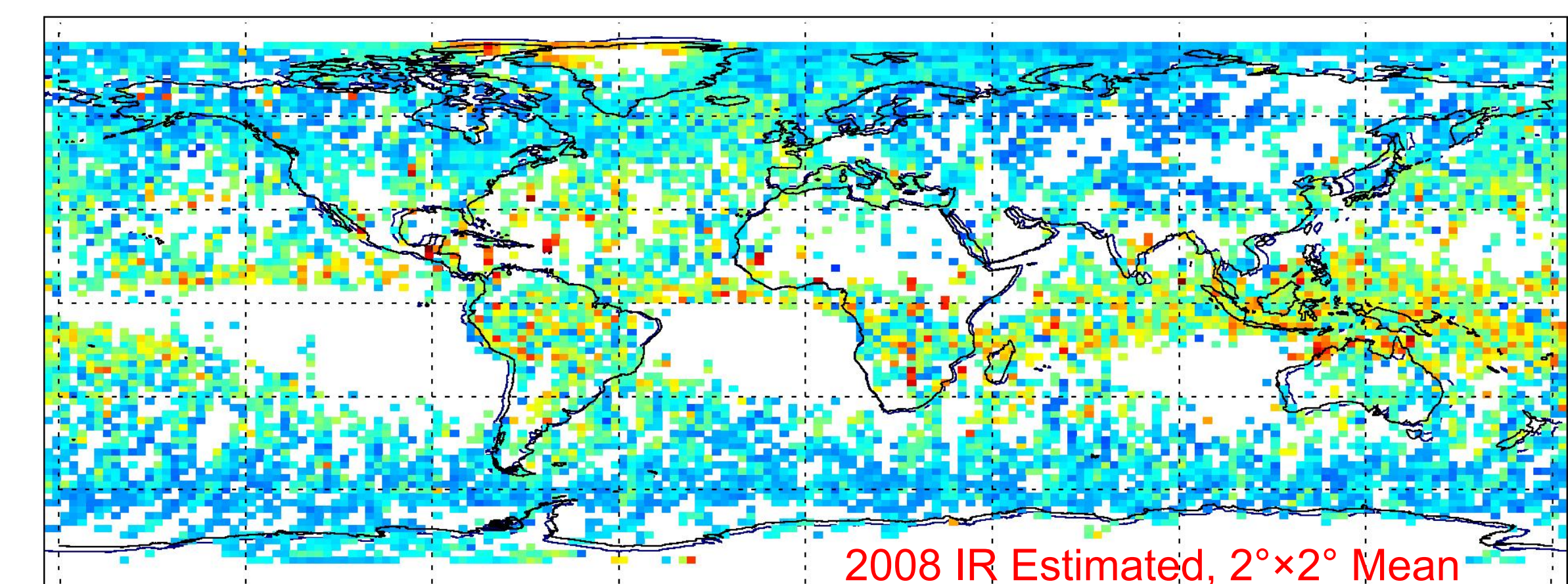
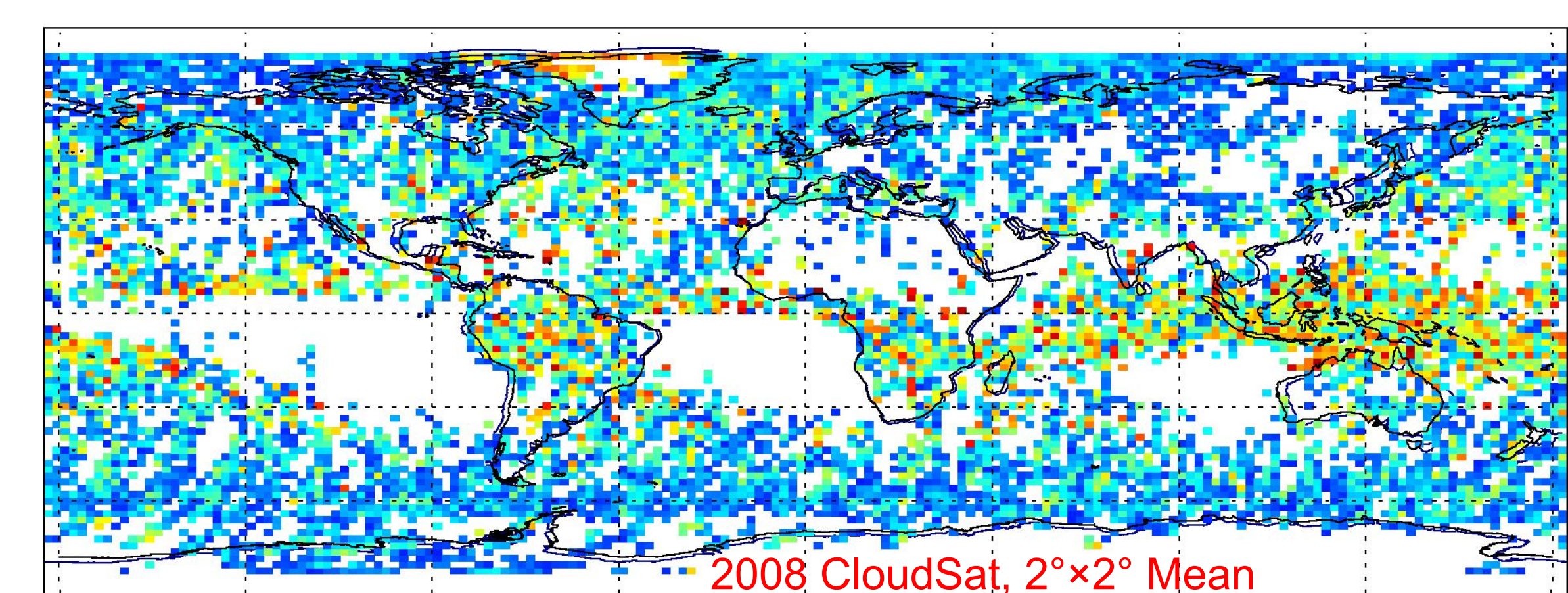
2008 Validation Data Scatterplot



Opaque Ice Cloud Nighttime Retrieval Example: COD



Geographical Distribution of Opaque Ice COD at Night



Visible Optical Thickness
10 100

- IR technique yields results relatively well correlated with CloudSat
- IR method overestimates smaller COD, underestimates larger values
- Bias = -0.3 and Std Dev = 13.5, RMS = 63%
- Despite large scatter, the information represents a large step forward in estimating COD at night for opaque clouds

Summary

- A combination of new and old algorithms that primarily rely on WV and IR channels can be used to estimate optical depths in ice clouds up to ~80 or so. This techniques were applied to MODIS data and the resulting ice CODs show good correlation with CO2-slicing and CloudSat-derived values. Non-opaque COD is unbiased on average with an RMS of 66%. Should help determine diurnal cycle of IWP.

- Additional research needed

- use with GEOSat data? how does viewing zenith affect the training?
- how much computer power required for its implementation?
- how does it relate to multilayered clouds?

References: Szejwach, G., 1982: Determination of semi-transparent cirrus cloud temperatures from infrared radiances: application to Meteosat. *J. Appl. Meteor.*, 21, 384.

Kato, S., F. G. Rose, S. Sun-Mack, W. F. Miller, Y. Chen, D. A. Rutan, G. L. Stephens, N. G. Loeb, P. Minnis, B. A. Wielicki, D. M. Winker, T. P. Charlock, P. W. Stackhouse, K.-M. Xu, and W. Collins, 2011: Computation of top-of-atmosphere and surface irradiances with CALIPSO, CloudSat, and MODIS-derived cloud and aerosol properties. Submitted to *J. Geophys. Res.*

Minnis, P., G. Hong, W. L. Smith, Jr., and P. W. Heck, 2010: Cloud optical depths at night: Going beyond the infrared blackbody limits. *2010 NOAA STAR AWG/RRR-Review*, Madison, WI, June 7-11.